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ORIGINAL ARTICLE

B-Flow Sonography for Evaluation of Basal Cerebral Arteries in Newborns

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Abstract The aim of the study was to evaluate the B-flow sonography (BFS) to image the basal cerebral arteries in newborn infants. For this purpose 34 newborns, who underwent standardized ultrasound of the brain including BFS, color Doppler (CDS) and power Doppler (PDS) techniques were retrospectively assessed. Delineation of the anterior communicating (Acom), the posterior communicating (Pcom), the middle cerebral (M1 and M2 segments), the anterior cerebral (A1 and A2 segments), and the posterior cerebral artery (P1 and P2 segments) were visually scored. Vessel delineation was better with BFS compared with CDS and PDS for the M2 segment ($p = 0.0006$ and $p = 0.0136$) and P2 segment ($p = 0.0021$ and $p = 0.0014$). Superior detectability was also noted for the Pcom with BFS compared with PDS ($p = 0.0062$). For all other vessel segments no significant differences were found. In conclusion BFS is feasible to image the basal cerebral arteries in newborns with an equal or better vessel delineation compared with standard vascular ultrasound methods.

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Introduction

Ultrasound is the primary modality for brain imaging in newborn infants. In contrast to magnetic resonance imaging (MRI) and computed tomography (CT), cerebral ultrasound can be performed at the bedside, without the need for sedation, contrast media or radiation. Insonation through the great fontanel or the temporal region allows high-resolution ultrasound images. Usually B-mode ultrasound is combined with Doppler-based methods to depict vascular anatomy and to exclude or characterize pathological conditions, such as arteriovenous malformations [1], arterial occlusive diseases [2], cerebral aneurysms [3], and tumors [4].

For vascular imaging, color Doppler (CDS) and power Doppler sonography (PDS) have been extensively studied. Both methods allow relatively exact imaging of the intracranial vessels [2, 5], visually controlled placement of the sample volume within a vessel, and Doppler angle correction for exact quantitative Doppler spectral analysis [2]; however, shortcomings of these Doppler methods are overestimation of vessel size (blooming artifacts), low signal from vessels with unfavorable insonation angle (insonation angle-dependence), and a limited dynamic range (mimicking artifacts) [6, 7].

These factors can limit exact visualization of complex vascular territories with small neighboring arteries and difficult to correct Doppler angles, such as in the neonatal basal cerebral arteries. More recently, alternative ultrasound-based techniques have been introduced for vascular imaging that operate on the basis of subtracting B-mode

images. One of them is B-flow sonography (BFS), which was first described in 2000 [8]. The BFS technique provides visualization of blood flow and therefore perfused blood vessels by amplifying weak flow reflectors (red blood cells) and suppressing the signals from the surrounding stationary tissue [9]. In our institution BFS has been used as a complementary ultrasound tool for approximately 4 years. Superior vascular imaging with BFS has been demonstrated in the hepatic vasculature [10], renal transplant vasculature [11], carotid [12, 13], and femoral arteries [14–16].

The aim of our study was to evaluate the feasibility of BFS to image the basal cerebral arteries in newborns and compare its performance with Doppler-based methods (CDS and PDS). Moreover, the performance in image analysis of offline BFS, CDS, and PDS cine scans is compared between an experienced and inexperienced observer.

Materials and Methods

Study Population

A total of 34 newborns admitted to the pediatric intensive care unit (13 girls and 21 boys, mean age 9.5 days, range 1–29 days, mean gestational age 36.2 weeks, range 29–41 weeks), who underwent cerebral ultrasound were retrospectively included in this study. Cerebral ultrasound revealed no pathologies in 27 patients. Other findings included cysts of the choroid plexus (n = 4), basal ganglia calcification (n = 1), enlarged brain ventricles (n = 1), and intracranial hemorrhage (n = 1).

The study was approved by the local ethics committee and the requirement for informed consent was waived. All examinations were conducted according to the Declaration of Helsinki.

Sonography

Ultrasound examinations were conducted by a radiologist with more than 8 years of experience (M.G.) with a GE Logiq 9 ultrasound system (GE Medical Systems, Milwaukee, WI) and a C1–6 probe with a frequency of 4.0 MHz. The ultrasound examination included the acquisition of CDS, PDS, and BFS cine scans by tilting the ultrasound probe in the transverse plane through the left or right temporal window.

Image Analysis

Evaluation of CDS, PDS, and BFS cine scans were performed offline and independently by two observers: observer 1 (experienced observer) was a consultant in radiology with more than 14 years experience in cranial sonography (J.H.), whereas observer 2 (inexperienced observer) was a resident in radiology in the fourth year but with no experience in cranial ultrasound (M.E.). Each reader was blinded to the other observer's assessments. A time interval of 4 weeks between the reading sessions of BFS, CDS, and PDS was maintained by each observer. Both observers re-evaluated the datasets again 10 months after evaluation to analyze intraobserver agreement. Now, the time interval between the reading sessions of BFS, CDS, and PDS was 2 weeks.

Delineation of the anterior communicating artery (Acom), the posterior communicating artery (Pcom), M1 segment of the middle cerebral artery (M1), A1 segment of the anterior cerebral artery (A1), and P1/P2 segments of the posterior cerebral artery (P1/P2) were rated using a 4-point scale:

- 0 = no vessel definable
- 1 = questionable vessel delineation
- 2 = incomplete vessel delineation
- 3 = complete vessel delineation

The M2 segment of the middle cerebral artery (M2) and A2 segment of the anterior cerebral artery (A2) were rated using a 5-point scale with the same grading as the 4-point scale plus an additional point (4 = complete vessel delineation with two distinguishable vessels) was applied. Before image evaluation, the observers received an instruction sheet to clarify rating criteria (Fig. 1). Moreover, the observers were trained with test cases, which were not part of the study population. All ratings were performed for vessel segments of the ipsilateral as well as the contralateral (c) side of insonation.

Statistical Analysis

Vessel delineation scores between BFS, CDS, and PDS were compared using a Mann-Whitney U-test. A p-value of less than 0.05 was considered to be significant. Mean scores with their standard deviations were calculated for all analyzed vessel segments.

Interobserver as well as intraobserver agreement for the experienced and inexperienced observer was evaluated using weighted Cohen kappa statistics. The results were interpreted as follows: 0.81–0.99 almost perfect agreement, 0.61–0.80 substantial agreement, 0.41–0.60 moderate agreement, 0.21–0.40 fair agreement, 0.01–0.20 slight agreement and <0.01 poor or less than chance agreement [17].

Statistical analysis was performed with commercially available software tools (MedCalc for Windows, Mariakerke, Belgium and Excel, Microsoft Corporation, Redmond WA).

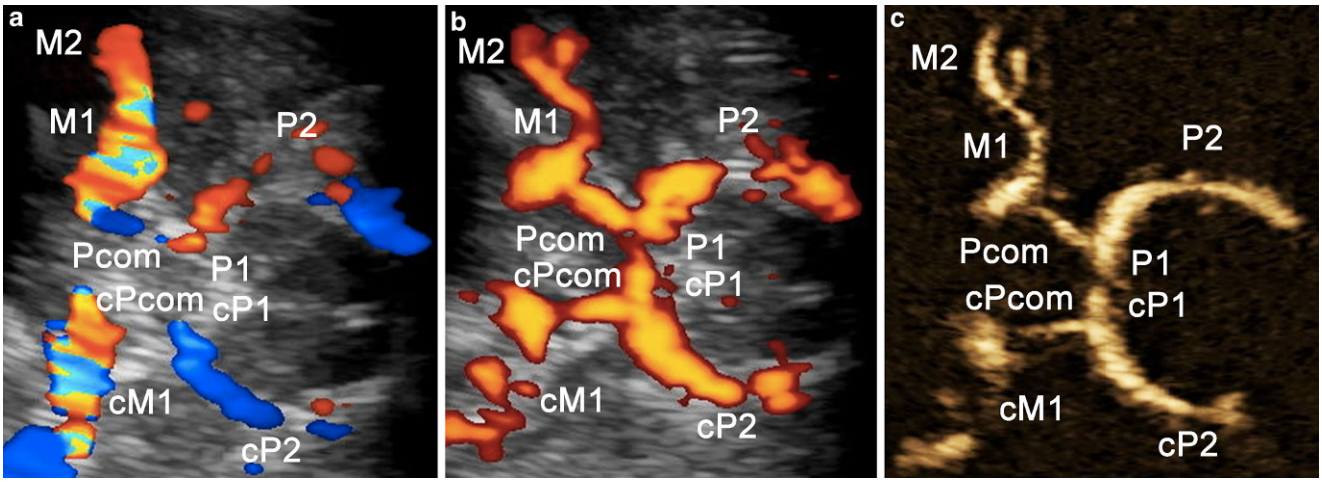

Fig. 1 Example figure to illustrate rating of vessel delineation for color Doppler (**a**), power Doppler (**b**), and B-flow sonography (**c**). Vessel segment ratings for the anterior (A), middle (M), posterior (P), and posterior communicating (Pcom) cerebral artery were determined as follows (c = contralateral side of insonation): **a** M1 = 3; M2 = 3; cM1 = 3; Pcom = 1; cPcom = 0; P1 = 0; P2 = 2; cP1 = 0; cP2 = 2. **b** M1 = 3; M2 = 4; cM1 1 = ; Pcom = 3; cPcom = 3; P1 = 1; P2 = 2; cP1 = 3; cP2 = 2. **c** M1 = 3; M2 = 4; cM1 1 = ; Pcom = 3; cPcom = 3; P1 = 3; P2 = 3; cP1 = 3; cP2 = 3. (anterior communicating artery as well as, A1, A2, and cM2 segments are not fully covered in the image plane)

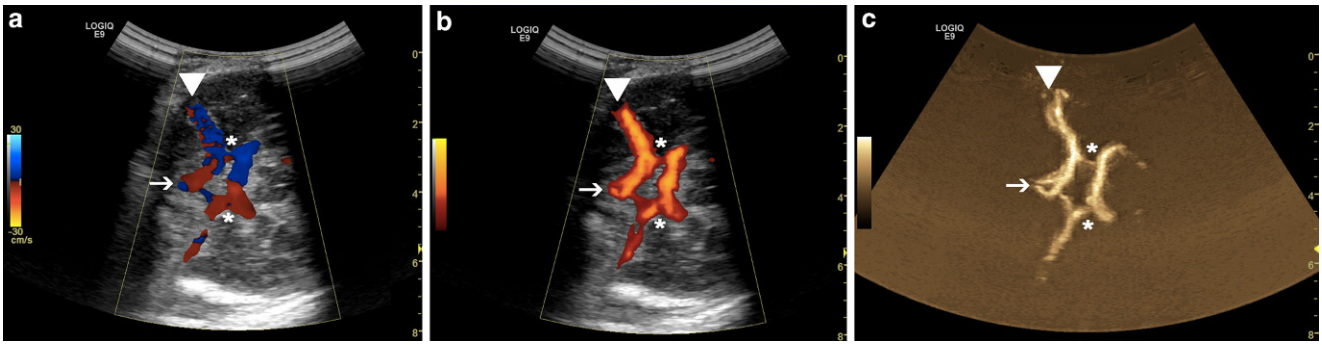

Fig. 2 Color Doppler (**a**), power Doppler (**b**), and B-flow sonography (**c**) of the basal cerebral arteries in a 1-day-old female newborn (gestational age of 33 weeks). In this case differentiation of two vessels performs better with B-flow sonography: A2 segment of the anterior cerebral artery (*arrow*) and probe M2 segment of the middle cerebral artery (*arrowhead*). Asterisks (*) mark posterior communicating arteries

Results

Comparison of BFS with CDS

The BFS showed higher vessel delineation scores for A2, M2, P2, Pcom, cM1, and cP2 compared with CDS (Fig. 2), becoming statistically significant only for M2 and P2 (p = 0.0006 and 0.0021). All other evaluated segments CDS and BFS revealed no significant differences (Table 1).

Comparison of BFS with PDS

A2, M1, M2, P1, P2, Pcom, cM1, cP1, cP2, and cPcom displayed better vessel delineation using BFS compared with PDS (Fig. 2). These differences were statistically significant for M2, P2, and Pcom (p = 0.0136, 0.0014 and 0.0062, respectively). All other vessel segments ratings showed no significant differences (Table 1).

Comparison of CDS with PDS

Except for a better vessel delineation of Pcom and cPcom for CDS (p = 0.0031 and 0.0192), no significant differences were found between CDS and PDS ratings regarding the other evaluated vessel segments (Table 1).

Intraobserver Agreement

Image evaluation intraobserver agreement for the inexperienced observer was substantial for CDS (0.74), PDS (0.78), and BFS (0.73). For the experienced intraobserver agreement was almost perfect for CDS (0.86), PDS (0.82), and BFS (0.92).

Table 1 Mean scores (±standard deviation) for identifiability of different segments of the basal cerebral arteries via temporal window: A1-/A2-segment of the anterior cerebral artery, M1-/M2-segment of the middle cerebral artery, P1-/P2-segment of the posterior cerebral artery, Acom, and Pcom

Segment	Mean scores			U-test (*p*-value)		
	BFS mean	CDS mean	PDS mean	BFS vs. CDS	BFS vs. PDS	CDS vs. PDS
A1	2.7 ± 0.54	2.8 ± 0.52	2.7 ± 0.64	0.2841	0.9879	0.4038
A2	2.3 ± 1.33	2.1 ± 1.09	2.1 ± 1.10	0.2907	0.2380	0.7976
Acom	1.4 ± 1.00	1.4 ± 1.10	1.6 ± 1.07	0.7337	0.0865	0.1060
M1	3.0 ± 0.12	3.0 ± 0.12	2.9 ± 0.33	x	0.1562	0.1250
M2	3.1 ± 1.13	2.5 ± 1.09	2.69 ± 1.39	*0.0006**	*0.0136**	0.0786
P1	2.9 ± 0.40	2.9 ± 0.52	2.8 ± 0.58	0.6250	0.1591	0.3028
P2	2.7 ± 0.59	2.4 ± 0.78	2.3 ± 0.74	*0.0021**	*0.0014**	0.5971
Pcom	2.2 ± 0.98	2.1 ± 1.12	1.7 ± 1.21	0.5806	*0.0062**	*0.0031**
cA1	2.5 ± 0.78	2.5 ± 0.67	2.5 ± 0.88	1.0	0.3289	0.4237
cM1	2.8 ± 0.48	2.7 ± 0.59	2.7 ± 0.66	0.3303	0.2293	0.9799
cM2	2.0 ± 1.47	2.3 ± 1.47	2.2 ± 1.31	0.0797	0.3232	0.4162
cP1	2.9 ± 0.48	2.9 ± 0.49	2.8 ± 0.61	1.0	0.2754	0.3750
cP2	2.6 ± 0.62	2.5 ± 0.70	2.5 ± 0.72	0.3681	0.0865	0.4683
cPcom	2.1 ± 1.03	2.2 ± 1.12	1.9 ± 1.19	0.3488	0.0900	*0.0192**

Acom anterior communicating artery, *BFS* B-flow sonography, *CDS* color Doppler sonography, *Pcom* posterior communicating artery, *PDS* power Doppler sonography, *c* contralateral to insonation side, *x* U-test was not possible (all scores were the same)
*Statistically significant

Interobserver Agreement

Interobserver agreement regarding the image evaluation (Cohen kappa) was moderate using CDS (0.48), PDS (0.57), and BFS (0.45). Mean vessel delineation scores obtained by the experienced vs. inexperienced observer were as follows: 2.5 vs. 2.5 using BFS, 2.4 vs. 2.5 using CDS, and 2.3 vs 2.4 using PDS.

Discussion

Imaging of the basal cerebral arteries in newborns was feasible with BFS and our results showed equivalent to superior delineation on the side of the insonation compared with the Doppler-based techniques. In contrast to CDS and PDS that tended to overestimate true vessel size due to blooming artifacts [6], BFS represents a B-mode sonography-based technique, which images vessel size true to scale [16] and without blooming artifacts [18]; therefore, one would expect benefits regarding the vessel delineation for BFS in regions where vessels are in close relationship to each other, such as A1, A2, Acom and M2. For insonation this assumption could be confirmed for A2 and M2, although the results were not statistically significant for A2.

On the contralateral side of insonation, delineation quality was not significantly better for the abovementioned vessel segments using BFS. This phenomenon may be explained by an inferior penetration depth of BFS compared with CDS and PDS. Furthermore, BFS is a less angle-dependent ultrasound technique [19]. Due to this characteristic, using the temporal insonation window, one would expect benefits of BFS in visualization of vessel segments proceeding vertically to the ultrasound beam, such as A2 and P2. Indeed, ipsilateral P2 showed significantly better vessel delineation, whereas A2 revealed a higher but not significantly better delineation score with BFS. A poor ultrasound window, which did not sufficiently cover A2 in some cases might be a reason for the non-significant difference for this segment.

Our results are of clinical relevance since ultrasound is usually the first imaging modality for various infantile cerebral vascular diseases [1–4]. In clinical routine CDS and PDS can help to distinguish perfused intracranial structures, such as a prominent ventricular plexus and tumors from structures without perfused vasculature, such as blood clots and ischemic lesions [20]. Moreover, CDS and PDS have been shown to enable evaluation of vascular anatomy including feeding vessels of intracranial arteriovenous malformations, such as vein of Galen malformations [21, 22]. After embolization of such arteriovenous malformations CDS and PDS are helpful tools for follow-up [22]. Since we could demonstrate that was often BFS superior to CDS and PDS, probably because of less angle dependent visualization of blood vessels and missing blooming artifacts, BFS might reveal sonographic advantages in discrimination and detection of vessels in such pathologic neurovascular conditions. Nevertheless, our study did not investigate any of the abovementioned neurovascular pathologies; therefore, further studies to evaluate the performance of BFS in dif-

ferent vessel involving cerebral diseases would be of great interest.

Differences in observer interpretation for cerebral pathologies with B-mode sonography subjected to observer's expertise have been investigated in a recent study [23] that showed better agreement in more experienced observers. Moreover, one of the main weakness of cranial vessel sonography is its operator dependency. The handheld technique requires detailed three-dimensional knowledge of cerebrovascular anatomy and its variations [24]. Our study showed moderate agreement for offline vessel delineation with cine scans using BFS, CDS, and PDS between two observers with different levels of expertise. While intraobserver agreement of the inexperienced observer was substantial for CDS, PDS, and BFS, the experienced observer showed almost perfect agreement. These results underline the observations by Hagmann et al. [23] and might explain the only moderate interobserver agreement in our study. A comparison of two experienced observers might have revealed a better interobserver agreement; therefore, interpretation of cerebral ultrasound loops seems to be more reliable with a higher degree of expertise; however, the possibility to scroll through a set of adjacent images instead of only a few selected ultrasound images might result in a more accurate evaluation for an experienced as well as an inexperienced observer. Therefore, in clinical routine, acquisition of movie data sets might help achieve a better interpretation of cerebral vessel topography by observers with different levels of expertise.

Some Limitations of our Study have to be Addressed

We retrospectively included only newborns in this study. Due to the progressive ossification of the infantile skull sutures and fontanelles [25], the temporal ultrasound windows get smaller with increasing age. The use of BFS may become more challenging in older patients. Our experience in clinical routine is that vessel detection with BFS in older patients might be inferior using BFS compared to CDS as well as PDS and a real benefit of BFS might only be expected in newborns; however, this has to be evaluated in further studies. Also up to the present, BFS is only available with ultrasound machines by one manufacturer and its use is therefore limited to a few institutions. A comparison of BFS with other ultrasound imaging techniques offered by different manufactures, such as superb microvascular imaging [26] as well as advanced dynamic flow [27] by Toshiba would be desirable. Such a comparison would be hard to perform, especially in newborns, as one patient has to be imaged with two different ultrasound machines during the same study. This approach would increase the duration of examination and would be intolerable for newborns.

Acquisition of CDS, PDS, and BFS movie scans, which were used for evaluation were only performed by either using left or right transtemporal insonation as our standard ultrasound protocol for sonographic evaluation of the cerebral vessels only included the acquisition of movie sequences from one temporal insonation side. The BFS performed worse when imaging vessels of the basal cerebral arteries which were on the contralateral side compared to the ipsilateral side of insonation; therefore, for optimal visualization of all vessel segments, the probe should have been performed through the left and right temporal windows.

Conclusion

In conclusion, BFS allows an equal or better imaging of basal cerebral arteries in newborns compared to CDS and PDS and might therefore represent a helpful complementary tool in the evaluation of pediatric cerebral vasculature in clinical practice. Moreover, acquisition of BFS, CDS, and PDS cine scans are recommended due to the high offline reliability in experienced and inexperienced hands.

Compliance with ethical guidelines

Conflict of interest M. Groth, M. Ernst, P. Deindl and J. Herrmann declare that they have no competing interests.

Ethical standards The study has been approved by the local ethics committee and the requirement for informed consent was waived. All examinations were conducted according to the Declaration of Helsinki from 1964 (in its current revised form).

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